Minimizing Human Risk: Human Performance Models in the Space Human Factors and Habitability and Behavioral Health and Performance Elements

Brian F. Gore[1]

[1] NASA Ames Research Center, Moffett Field, CA 94035-0001
Brian.F.Gore@nasa.gov

Abstract. Human space exploration has never been more exciting than it is today. Human presence to outer worlds is becoming a reality as humans are leveraging much of our prior knowledge to the new mission of going to Mars. Exploring the solar system at greater distances from Earth than ever before will possess some unique challenges, which can be overcome thanks to the advances in modeling and simulation technologies. The National Aeronautics and Space Administration (NASA) is at the forefront of exploring our solar system. NASA's Human Research Program (HRP) focuses on discovering the best methods and technologies that support safe and productive human space travel in the extreme and harsh space environment. HRP uses various methods and approaches to answer questions about the impact of long duration missions on the human in space including: gravity's impact on the human body, isolation and confinement on the human, hostile environments impact on the human, space radiation, and how the distance is likely to impact the human. Predictive models are included in the HRP research portfolio as these models provide valuable insights into human-system operations. This paper will provide an overview of NASA's HRP and will present a number of projects that have used modeling and simulation to provide insights into human-system issues (e.g. automation, habitat design, schedules) in anticipation of space exploration.

Keywords: Space Human Factors & Habitability · Human Performance · Human-Systems Integration · Systems Engineering · Modeling and Simulation

1 Introduction

The United States' Department of Defense (US DoD) and the National Aeronautics and Space Administration (NASA) put humans in extreme and hostile environments and require the human to perform optimally in order to successfully accomplish mission goals. Sub-optimal performance in the US DoD and NASA missions has the potential to increase the risks of not completing the mission successfully. A variety of methods to predict human-system vulnerabilities are needed to effectively manage such risks.

Our nation’s space program has grown in sophistication and ambition over the recent past. The NASA Human Research Program (HRP) is the result of efforts undertaken by the agency to refocus its efforts on space exploration from the efforts of the Constellation program. The US space program has transitioned from one that focused on completing the International Space Station, to returning to the Moon, to crewed flight to the planet Mars, to one of exploration at greater distances and longer durations from planet Earth with the goal of traveling to Mars and beyond. This focus on exploration has changed the activities that NASA has been undertaking to include activities beyond low Earth orbit (LEO) over a longer duration. The NASA Programs responsible for insuring that success will be attained include the management of Commercial Space Transportation, Exploration Systems Development, Human Space Flight Capabilities, Advanced Exploration Systems, Research and Technology, and Operations.

2 NASA’s Human Research Program

The Human Research Program (HRP) resides under NASA’s Research and Technology program. The goal of the HRP is to provide human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration [1]. The HRP and its researchers are working to develop capabilities, necessary countermeasures, and technologies to support human space exploration, focusing on mitigating the highest risks to crew health and performance and documenting these findings in guidelines and standards. In addition, HRP seeks to develop technologies that serve to reduce medical and environmental risks, to reduce human systems resource requirements (mass, volume, power, data, etc.), and to ensure effective human-system integration across exploration mission systems. HRP ensures maintenance of Agency core competencies necessary to enable risk reduction in the following areas: space medicine; physiological and behavioral effects of long-duration spaceflight on the human body; space environmental effects (including radiation) on human health and performance; and space human factors. The HRP and its researchers are working to improve astronauts' ability to collect data, solve problems, respond to emergencies, and remain healthy during and after extended space travel. Investigators in HRP work to predict, assess, and solve the problems that humans encounter in space through national and international assets and collaborations.

2.1 NASA HRP Structure

As of June 1, 2016, HRP is made up of six elements: International Space Station Medical Project, Space Radiation, Human Health Countermeasures, Exploration Medical Capability, Behavioral Health & Performance, and Space Human Factors and Habitability. The six Elements are aimed at exploring many facets of human space travel including Environmental Factors, Exercise Physiology, Habitability, Human Factors, Medical Capabilities, Physiology, Psychosocial and Behavioral Health, and Space Radiation. The HRP’s six Elements enable scientists and engineers work to predict, assess, and solve the problems that humans encounter in space.

The HRP and its six elements use a risk reduction strategy based on a medical model to guide the research that is to be conducted. The HRP focuses its research investment on investigating and mitigating the highest risks to astronaut health and performance in support of exploration missions. This process describes evidence as the basis for the existence of a risk to the human system, gaps in our knowledge about characterizing or mitigating the risk, and the tasks that need to be carried out in order to produce the deliverables needed to close the gaps and reduce the risk. The evidence for the existence of the risk is documented in the risk Evidence Reports, the gaps in knowledge represent the questions that need to be answered to mitigate the risk, the tasks characterize the risk or develop mitigation capabilities to reduce the risk to an acceptable level, and deliverables culminate in the final product (standards, guidelines, countermeasures). HRP relies on Design Reference Missions (DRMs), which provide a framework to identify key capabilities and important guiding drivers and assumptions, thus enabling the HRP to focus its research questions on topics highly relevant to NASA's future activities. The exploration missions currently considered include the International Space Station (ISS), lunar, near Earth objects/asteroids, and Mars missions [1].

2.2 Methods Used to Minimize Human Exploration Risks

The multiple lines of critical research that needs to be undertaken by NASA's HRP require that a suite of approaches be used to predict the impact of the complex, long duration mission on the human, and on the human's ability to perform. Ground research occurs in laboratories and analogs that simulate a portion of the spaceflight environment. The International Space Station (ISS) is used to conduct research requiring the unique environment of space, and for validating some of the results from ground-based studies. NASA has also adopted the NASA-STD-3001 to establish a broad set of criteria that ensures that humans are healthy, safe, and productive in space. The approaches used to meet these criteria need to include both the concerns from the human physiology and medical procedures and standards for maintenance and preservation of health, as well as the 'systems' perspective. Specifically, systems that interface with the human: controls, displays, architecture, environment, and habitability support systems. NASA uses a variety of methods to optimize designs for all crew operations both inside and outside the spacecraft in space and on lunar and planetary surfaces. The charter of the Space Human Factors and Habitability (SHFH) Element is to perform the research and technology development to enable documentation and validation of the environmental and human factors standards within NASA-STD-3001, NASA Space Flight Human Systems Standard, Vol. 2, and the Human Integration Design Handbook [2,3]. The SHFH Element is further subdivided into the Advanced Food Technology, the Advanced Environmental Health, and the Space Human Factors Engineering projects.

2.3 HRP Risk Statements

Six risk statements exist within HRP's SHFH Element and serve to guide the research that is completed in order to optimize human performance in space [4]. These statements follow.

Risk of Incompatible Vehicle/Habitat Design (HAB). Given that vehicle, habitat, and workspace designs must accommodate variations in human physical characteristics and capabilities, and given that the duration of crew habitation in these space-based environments will be far greater than mission of the past, there is a risk of acute and chronic ergonomics-related disorders, resulting in flight and ground crew errors and inefficiencies, failed mission and program objectives, and an increase in the potential for crew injuries.
Risk of Inadequate Design of Human and Automation/Robotic Integration (HARI). Given that automation and robotics must seamlessly integrate with crew, and given the greater dependence on automation and robotics in the context of long duration spaceflight operations, there is a risk that systems will be inadequately designed, resulting in flight and ground crew errors and inefficiencies, failed mission and an increase in crew injuries.
Risk of Performance Errors due to Training Deficiencies (TRAIN). Given that existing training methods and paradigms may inadequately prepare long-duration, autonomous crews to execute their mission, there is a risk that increased flight and ground crew inefficiencies, failed mission and program objectives, and increased crew injuries will occur.
Risk of Inadequate Mission, Process, and Task Design (MPTASK). Given that tasks, schedules, and procedures must accommodate human capabilities and limitations, and given that ling-duration crews will experience physical and cognitive changes and increased autonomy, there is a risk that tasks, schedules, and procedures will be developed without considering the human condition, resulting in increased workload, flight and ground crew errors and inefficiencies, failed mission and program objectives and an increase in crew injuries.
Risk of Inadequate Human Computer Interaction (HCI). Given that human-computer interaction and information architecture designs must support crew tasks, and given the grater dependence on HCI in the context of long-duration spaceflight operations, there is a risk that critical information systems will not support crew tasks effectively, resulting in flight and ground crew errors and inefficiencies, failed mission and program objectives, and an increase in crew injuries.
Risk of Injury from Dynamic Loads (OP). Given the range of anticipated dynamic loads transferred to the crew via the vehicle, there is a possibility of loss of crew or crew injury during launch, abort, and landing.

Both empirical and computational approaches have been used iteratively to reduce the impact of risks to human exploration.

3 NASA's Human Research Program Use of Modeling and Simulation

Modeling and simulation (M&S) techniques play an integral role when complex human-system notions are being proposed, developed, and tested. NASA Johnston Space Center (JSC) utilizes M&S to represent environments, physical structures and equipment components, crew stations, planets and planetary motions, gravitational effects, illumination, human anthropometric and biomechanics. NASA Ames Research Center utilizes M&S capabilities for airflows, flight paths (e.g., Airspace Concept Evaluation System-ACES), aircrafts, schedules (e.g., Core-XPRT, Science Planning InterFace to engineering − SPIFe, Playbook), human performance prediction (HPMs; e.g. MIDAS), and bioinformatics. NASA's SHFH currently uses a number of these M&S approaches to estimate many aspects critical in the human research roadmap (HRR) in the respective risk's Path to Risk Reduction (PRR) [5].

Eight HRP SHFH projects currently underway (or recently completed) serve to reduce gaps in knowledge in the habitability, task design, human automation and robotics integration, and the behavioral health and performance sleep risks illustrate the manner that M&S approaches have been used to inform the respective risk.

3.1 Computational Model for Spacecraft/Habitat Volume

The Computational Model for Spacecraft/Habitat Volume task set out to create a "bottoms-up" method based on mission attributes and critical task volumes better align with a human-centered design philosophy than the top-down approach that is commonly used [6]. The objective of this ongoing work is to develop a constraint-driven, optimization-based model that can be used to estimate and evaluate spacecraft/habitat volume. The computational model development aims to: Estimate spacecraft/habitat volume based on mission parameters and constraints, provide layout assumptions for a given volume, assess volumes based on a set of performance metrics, and inform risk characteristics associated with a volume. The outcome of this work will directly answer to HRP's Risk of Incompatible Vehicle/Habitat Design and the associated Space Human Factors Engineering (SHFE) SHFE-HAB-09 Gap on technologies, tools, and methods for data collection, modeling, and analysis for design and assessment of vehicles/habitats. This ongoing work is expected to continue through 2017.

3.2 A Tool for Automated Collection of Space Utilization Data

The tool for automated collection of space utilization data task is designed to develop innovative methods to unobtrusively collect detailed and high quality input data without impacting crew time or constraining missions [7]. The objective of this ongoing work is to develop and validate an automated data collection system that delivers data useful in the analysis of space utilization and vehicle habitability pertaining to crew activities on the ISS as well as potential long duration space missions. The investigation utilizes two independent technologies, 3D RFID-Real Time Location System (RTLS) and Microsoft Kinect 3D volumetric and anatomical scanning tools, and inte-

grates them into a single data collection and integration solution. The project advances the integrated system through a validation exercise that uses the HRP Human Exploration Research Analog (HERA) platform. The significance of this task is that it will provide NASA with a quantitative methodology for collecting data 3D space utilization data that is validated for use in flight analogs and has potential direct applicability for use in in-flight environments. The outcome of this research will provide some insight into HRP's Risk of Incompatible Vehicle/Habitat Design and the associated Space Human Factors Engineering (SHFE) HAB-05: We need to identify technologies, tools, and methods for data collection, modeling, and analysis that are appropriate for design and assessment of vehicle/habitats by creating a capability to automatically collect space utilization and other habitation-related questions, questions that need to be answered as the mission lengths increase to months-long durations.

3.3 Human – Automation Interactions and Performance Analysis of Lunar Lander Supervisory Control

This task examined the complex interactions between the astronauts and the vehicle systems and automation required to conduct safe and precise planetary landing tasks. The task produced an integrated human-system model that includes representations of human attention, perception, decision-making, and action for use as an early-stage simulation-based design tool for human-system integration in complex systems [8]. The case study was a piloted lunar landing task. There were four integrated specific aims: (1) Perform a critical analysis of human operator-automation interactions and task allocations, considering information requirements, decision making, and the selection of action; (2) Develop a closed-loop pilot-vehicle model, integrating vehicle dynamics and human performance models, and parametrically analyze and quantify system performance; (3) Conduct experiments in the Draper Laboratory fixed-base simulator to validate critical parameters within the integrated pilot-vehicle model; (4) Extend the model to include the effect of spatial orientation and conduct experiments on the NASA Ames Research Center (ARC) Vertical Motion Simulator (VMS) to investigate the effects of motion cues on pilot performance. The results of the VMS and Draper Laboratory experiments have been used to update the integrated human-system model of the lunar lander. The model represents the cognitive processes and action responses of the human, who can act as both a flying pilot as well as a supervisory pilot. The model blocks have been updated in the Human Performance Model (HPM) library, and the integrated model has been used to run sensitivity analyses to the effect of parameter variation on simulated system performance. The outcome of this research answered HRP's Risk of Inadequate Mission, Process, and Task Design and the associated Space Human Factors Engineering (SHFE) gap MPTASK-01: we need methods and tools to collect measures of mission, process, and task performance.

3.4 MIDAS-FAST: Development and Validation of a Tool to Support Function Allocation

The MIDAS-FAST[1] project examined the impact that automation has on human manual control performance of a robotic asset, the International Space Station Mobile Servicing System (Canadarm 2) [10]. Robotic manipulations are complex and often involve moving the arm in 7 degrees of freedom, with rotation up to 540 degrees, often possessing optimal camera viewing angles presented on the Advanced Space Vision System screen that need to be set by the crewmember. "Automation" has been proposed as a solution to assist the human guard against errors, which can have disastrous, potentially life threatening, consequences.

The MIDAS-FAST project uses human-performance models with a robotic simulation environment to evaluate the effects of function allocation strategies and task type on operator and system performance in order to evaluate potential human-automation interaction design issues. In this task, the research team 1) developed and validated a model- and simulation-based tool to allow researchers to evaluate various function allocation strategies in space robotics missions and 2) conducted empirical research to investigate human-automation interaction (HAI). The tool used the Man-Machine Integration Design and Analysis System (MIDAS, a NASA Ames HPM tool) [11], the Basic Operational Robotics Instructional System (BORIS, a NASA Johnson Space Center (JSC) training simulation [12], and the Frame of Reference Transformation (FORT) model. FORT was added to the operator model to identify the quality of camera views and control-movement compatibility [13]. FORT contributes to the operator workload, calculated in the human performance software, MIDAS. MIDAS-FAST provides ways for the modeled operator to 1) receive and interpret data from BORIS, 2) assess their own performance as the task is carried out, and 3) adjust their behavior based on FORT and external (BORIS-driven) stimuli.

The MIDAS-FAST task provided a validated model- and simulation-based tool for predicting operator performance when working with a robotic arm in different function allocation situations. The function allocation model, and the empirical research in this effort were used to identify conditions and provide data to develop the tool. The MIDAS-FAST task has integrated the FORT, BORIS and MIDAS models and has developed a combined user interface. The outcome of this research addressed HRP's Risk of inadequate design of human and automation/robotic integration and the associated Space Human Factors Engineering (SHFE) gap HARI-01 we need to evaluate, develop, and validate methods and guidelines for identifying human-automation/robot task information needs, function allocation, and team composition for future long duration, long distance space missions [14].

3.5 Modeling and mitigating spatial disorientation in low g environments

The goal of this task was to extend a spatial disorientation mitigation software developed for aeronautical use called Spatial Disorientation Analysis Tool (SDAT) to NASA's space applications (e.g. the Shuttle, crew exploration vehicle, Altair, and

[1] The MIDAS-FAST project arose from the workload monitoring and modeling task of the HRP SHFE portfolio from 2008-2010 [9].

Mars exploration missions) [15]. This task served three main goals: 1) Enhance the utility of SDAT/SOAS by including appropriate mathematical models for vestibular and visual sensory cues, and CNS (central nervous system) gravito-inertial force resolution into perceived tilt and translation estimates from Massachusetts Institute of Technology's (MIT's) Observer model, and revalidating it using existing aeronautical data sets. 2) Extend the models to describe 0-G, Shuttle, and Altair landing illusions, validating the models using Shuttle and Altair simulator data sets, and current theories (e.g., ROTTR). 3) Extend SDAT/SOAS to consider multiple visual frames of reference, the effects of visual attention and sensory workload, and the cognitive costs of mental rotation and reorientation. The enhanced SDAT/SOAS were validated via simulator experiments. Four key findings from this research were as follows. 1) MIT's Observer model was merged with SDAT; (2) SDAT was enhanced with an attention model termed N-SEEV (noticing-salience, expectancy, effort, and value) and with three new illusion models, verification tests, and comparisons of analytical results produced by SDAT and Observer; (3) SDAT was validated with anonymous data sets of helicopter pilots who experienced spatial disorientation (SD); and (4) an Institutional Review Board (IRB)-approved Space Shuttle spatial orientation survey was completed. The outcome of this research answers a part of HRP’s Risk of Inadequate Human-Computer Interaction and the associated Space Human Factors Engineering (SHFE) gap HCI-03 we need HCI guidelines (e.g., display configuration, screen-navigation) to mitigate the performance decrements and operational conditions of long duration space.

3.6 Space Performance Research Integration Tool (S-PRINT).

The purpose of the Space Performance Research Integration Tool (S-PRINT) task was to build off of earlier validated human performance model work (e.g. MIDAS-FAST) to develop tools and empirically-based guidelines that support human performance researchers, mission planners, automation designers, and astronauts in long-duration missions, specifically human performance in unexpected workload transition situations [16]. These situations, when addressed by fatigued astronauts, constitute worst-case scenarios that require specific, in-depth investigation. S-PRINT helps users anticipate and avoid potential problems related to unexpected workload transitions by identifying the expected effects of operator fatigue, automation system design, and task factors on overload performance, and assure that systems can be designed in such a way as to minimize transient, and long-term impacts of space missions on performance.

The S-PRINT task provided a validated, model-based tool to help researchers evaluate potential long-duration missions, identify vulnerabilities, and test potential mitigation strategies to help ensure effective performance and safe space missions. In addition to the meta-analyses, the project included multiple human-in-the-loop (HITL) studies to investigate 1) human-automation interaction (exploring, in particular, the effects of automation design factors and failure types on automation bias and complacency), 2) multitasking in overload situations. The results of these studies have been published and contribute to the scientific knowledge in human-automation interaction and human performance in overload. These two topic areas are relevant in numerous Earth-based domains.

The S-PRINT task also developed component models that enable the software to predict; 1) the effects of fatigue (i.e., due to sleep deprivation, sleep restriction, sleep inertia, and circadian cycle effects) on task completion time and task accuracy, 2) the effects of automation design factors (e.g., reliability, degree of automation or function allocation) on operator performance, 3) the effects of failure type on operator performance, and 4) the effects of task factors (i.e., salience, expectancy, effort, and value) on task selection in overload. All of these areas are relevant in Earth-based industries that require around-the-clock operations, involve the use of automation, and offer the potential for situations that put an operator in overload conditions (e.g. medicine, process control, military operations, and transportation). The outcome of this research adds an approach that can be used HRP's Risk of inadequate mission, process, and task design and the associated Space Human Factors Engineering (SHFE) gap MPTASK-01: We need methods and tools to collect measures of missions, process, and task performance, and Behavioral Health and Performance (BHP) gap Sleep 8 we need to develop individualized scheduling tools that predict the effects of sleep-wake cycles, light and other countermeasures on performance, and can be used to identify optimal (and vulnerable) performance periods during spaceflight [17].

3.7 Occupant protection Data Mining and Modeling

The risk of injury due to dynamic loads is poorly understood for spaceflight [18]. It is necessary that the risk to crew members associated with dynamic loads be reduced. Many differences exist between the well-documented automotive and military environment (NHTSA, MILSPEC) and those experienced in space flight operations. For instance, the loads experienced in space flight are often a multi-axial, complex impact that is unique to a particular vehicle design, which differences from terrestrial vehicles. Limitations of the current NASA standard require that: 1) a Finite Element (FE) model of test device for Human Occupant Restraint (THOR) Anthropometric Test Device (ATD) be developed, and 2) data mining of existing human injury and response data using the THOR FE model be performed. The purpose of the OP task therefore is to define the scope of dynamic loads reasonably expected in current and future spaceflight systems, identify the appropriate human surrogate(s) for implementing injury assessment reference values (IARVs) appropriate for spaceflight loading conditions, develop IARVs based on Definition of Acceptable Risk (DAR), and validate the IARVs through sub-injurious human testing at nominal landing loads.

In order to develop updated standards, adequate injury assessment tools must be completed. The THOR ATD was chosen as the appropriate human surrogate as it is the most biofidelic ATD available for assessing dynamic loads [18]. The THOR ATD is limited as the THOR responses are not well correlated to low injury risk. New injury risk functions are therefore needed. The OP risk sets out to develop new functions by comparing the THOR ATD datasets against existing datasets from Wright Patterson Air Force Base and the National Highway Transportation Safety Administration. The data mining portion of the task, requires that each impact case be recreated to determine injury risk. Physical recreation of all impact cases is not feasible. A numerical model of the THOR ATD is being generated since physical recreation of each case is not feasible. An existing THOR FE model is being refined and validated. Additional THOR ATD testing will be conducted at two facilities and ATD response

data will be collected to supplement the available THOR ATD validation data. The FE model responses will then be assessed against the physical ATD responses. Once the ATD model is validated, it will be used in the data mining portion of the study. This task contributes to OP-02 and OP-03 by developing an ATD analytical model.

4 Discussion

NASA's HRP needs to study the impact of long duration space flight on human crew members without the luxury of limitless access to the space environment. This fact requires multiple, cooperative approaches to predict when humans will be able to perform optimally and the situations that occur that tax the human capacity for optimal performance. HRP is investing resources into developing valid, predictive capabilities in the modeling and simulation domain. The current article highlights that HRP SHFH has developed models in the HAB, MPTASK, HARI, HCI and OP research areas that seek to reduce the risks to exploration class mission operations.

The computational model development aspect the Habitability risk aims to provide NASA with estimates on the spacecraft/habitat volume based on mission parameters and constraints, provide layout assumptions for a given volume, assess volumes based on a set of performance metrics, and inform risk characteristics associated with a volume. This research will establish the minimum volume required for personal space, exercise, sleep, eat, work and relaxation. Distinct areas for each activity are not going to be possible so NASA is looking to predict the minimum space required to safely conduct the mission. Two ongoing modeling and simulation task in the Habitability risk aim to establish recommendations for future vehicle design layout and minimum net habitable volume (NHV).

The computational model development aspect of the HARI risk aims to develop, and validate methods and guidelines for identifying human-automation/robot task information needs, function allocation, and team composition for future long duration, long distance space missions. One validated model- and simulation-based tool for predicting operator performance when working with a robotic arm in different function allocation situations provided NASA with the capability to augment and perform model manipulations to evaluate different function allocation strategies for future human-robotic systems. This one effort is a necessary step and it is anticipated that future efforts build on the lessons learned by the MIDAS-FAST research team for future function allocation (and HARI) related research tasks.

The computational model development aspect of the HCI risk aims to mitigate the performance decrements and operational conditions of long duration space operations. HCI approaches often require optimization of interface designs so that human performance is maximized. HCI and interface designs rely on the human's ability to receive and encode the information that is presented. In order for this encoding to occur, the human needs to be aware of the information and to attend to the information. As the human's autonomy increases, attention allocation takes on an increasingly important role for critical information intake. The outcome of this research has provided insights into human performance capability in the face of spatial disorientation in microgravity. The attention allocation model that was developed in response to this HCI risk

serves as the backbone to many HPMs in use across the field of modeling and simulation.

The computational model development aspect of MPTASK risk aims to reduce the risk to mission performance that are the result of inefficiencies caused by the task, schedule, or procedure design. Two modeling and simulation efforts have been recently completed that address aspects of this very large risk area. The S-PRINT task provided model-based human performance predictions on the effects of automation design factors and failure types on automation bias, and the impact of complacency and multitasking in operator "overload" conditions. This effort produced a general model capability that can be modified with different automation types to examine the impact of context and situation demands on operator performance with the main focus on transitions between overloaded and under-loaded individuals. The interest in this effort was to implement a fatigue model into a human performance model for use by mission schedulers. The scenario that exercised the automation designs was a robotic arm control while dealing with an environmental control and life support system fault. The second MPTASK modeling effort was of a piloted lunar landing task. This effort completed a critical analysis of human operator-automation interactions and task allocations for lunar landing operations (information requirements, decision making, and the selection of action), and developed and validated a closed-loop pilot-vehicle model, integrating vehicle dynamics and HPMs.

The computational model development aspect of the OP Risk aims to reduce the risks associated with dynamic loads. One modeling and simulation effort is underway for the OIP risk. The OP computation model development is a practical example that illustrates how existing validated datasets can be leveraged to support modeling and simulation approaches to improve algorithms for predicting human performance.

As illustrated in the present article, many distinct modeling and simulation efforts are being completed by NASA's HRP. The investments that have been made in modeling and simulation have already and will continue to provide NASA with a number of validated capabilities. Possessing such capabilities may allow NASA to consider integrating the models together (where feasible) to generate integrated human-system model performance predictions.

5 Conclusions

Extreme and hostile environments require the human to perform optimally in order to successfully accomplish mission goals. Sub-optimal performance in the US DoD and NASA missions has the potential to increase the risks of unsuccessful mission operations. It is only with a comprehensive research program that includes both the empirical research efforts complemented with a modeling and simulation research path that the designs of the habitability, human computer interaction, human automation integration, task and occupant protection will successfully enable the human to perform in extreme environments, such as the one that will be faced in the travel to Mars.

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